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EVOLUTION OF KIRIGAMI AND ORIGAMI TOWARDS ARCHITECTURAL CONCEPT DEVELOPMENT- A REVIEW

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ABSTRACT

Origami, from 'oru', meaning 'fold' and 'kami', meaning `paper', is an ancient Japanese art of making objects for decoration by folding sheets of paper into shapes and forms without joining with adhesives. While kirigami involves folding and cutting of papers and modelling boards joined together with adhesives as a relief. Origami and kirigami structures at the micro/nanoscale in relation to architecture were established as a conceptual

Introduction

Origami, voronoi, miura-ori and tessellation are past-recent terminologies used interchangeably in architecture and engineering but have their generic and specific meanings. Origami, from 'oru', meaning 'fold' and 'kami', meaning `paper', is an ancient Japanese art form that can be traced back to the 17th century (Ingenia, 2014). Voronoi diagrams on the the hand are a way of dividing spaces formed based on a series of point which makes the space organized (Fatemeh and Kian, 2014). While miura-ori is a flat-foldable origami tessellation with a wide range of engineering applications (Pooya and Simon, 2015). Tessellations are sometimes referred to as "tilings". Strictly however, the word tiling refers to a pattern of polygons (shapes with straight sides) only. Tessellations (types and forms) can be formed from regular and irregular polygons,

system suggesting further use of both techniques and methods for exploring the transformation of three-dimensional entities in the design of spatial structures. In Islamic art and Japanese architecture, origami plays a very important role in the evolution of design thoughts both in theory and practice. As a result of the above, this paper is aimed at studying the various concept development in architecture, using origami and kirigami. The methodology entails qualitative analysis by both compare and contrast method, using the iterations at the general views and specific views vis- a-vis the raised questions. As a result of the above, this paper reviews as well as appraises the issues such as innovative designs systems, bio-architecture (biophyllic, biomimicry, e.t.c) amphibian architecture systems, digital intelligent building systems, 3d printed homes or hybrid, vertical and modular systems etc. for implementation in day-to-day architectural concept development.

Keywords: *art, concept, building, transformation, theory and practice*

making the patterns they produce yet more interesting (Khaira, 2009). Tessellation according to Lisa (2013) refers to both tiled patterns in building elements and digitally defined mesh patterns (creative weave). Tessellations in nature can be found in animals and plants such as giraffe, spider, tortoise, fish, pineapple and colchicum flower. As a result of such inspirations, Rubik, a Hungarian Professor of Architecture thus designed tessellated jig-saw puzzle, magic cube and computer game of diverse applications (Ann, 2013). Connections between origami and kirigami were established as a concept systems suggesting further use of their techniques and methods for exploring the use of three-dimensional entities in the design of spatial structures. Typical examples of origami are voronoi tessellations and miura-ori tessellations, which evolves a great idea developed into geometrical interlocking shapes or form to produce a modular template. Transformable architecture according to Katherine (2002), narrated that the use of membrane packaging has been the main feature of the earliest prototypes of similar concepts of spatial transformation encountered in the origami art where a planar paper surface, after folding, transforms to a 3-dimensional object. Because membranes in general can be considered surfaces of minimal thickness, principles of the origami art and mathematics can find applications in the conception and design of transformable membrane structures for architecture. Her two-case study has shown how origami mathematics is integrated in the computer visualization and kinematic simulation of these structures, and how animated simulations of the transformation process during folding can identify problems in their initial geometric conception. Apart from art and architecture, the contributions of some aspects of Physics and Mathematics (geometry, triangulation, algorithm, decimation, algebra, circle theory) and Computer can never be under estimated in the growth and development of origami. As a result of the above, this research is aimed at studying the various applications of origami based concepts in architecture. General examples of origami and kirigami in practice include roofs, shells, geo-textile filters, precast modular concrete honey comb pattern-accropodes, interlocking tiles, walls, and ceilings of various materials, etc. Specific examples of origami concepts include voronoi tessellations, miura-ori tessellations, meshes, simulations, modellings, robotics, digital effects, and 3D printing, etc. Uncommon development in the context of architecture and origami could best be described by the recent trends in the design of buildings, which is to design and construct buildings that are sustainable to their host environment. A major breakthrough in the design of green/sustainable buildings is the use of Building Information Modelling BIM to not only visualize the proposed design in 3D but to also layer the design with additional project information, where there are 4^{th} and 5^{th} dimensions of time and cost (Musa, Aliyu & AbdulMageed, 2014).

LITERATURE REVIEW

The Origami House (**Fig**. 1 & 2) is planned so that the internal space wrapped in the origami roof. The architect places the living room and dining room in the centre of the house to utilize internal space and locates other rooms (kitchen, Japanese-style room, bedroom, and bathroom) to surround it. The house is framed by its angular roof, which is folded in five places to create a series of triangular facets. The roof meets the ground at several points around the perimeter, creating a form that envelops the interior. The origami roof stands from the earth like a tent, creates tolerant space and protects the life of the family. In addition, the origami roof has various functions. It controls sunlight and takes in wind and, besides, makes half outdoors space. The diagonal roof

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becomes stronger by contacting with the ground, and it is effective for wind pressure, earthquake. Not only as a shelter which protects a family from a wind and rain, has the diagonal roof functioned also as a structure (Yoshiaki, 2014).

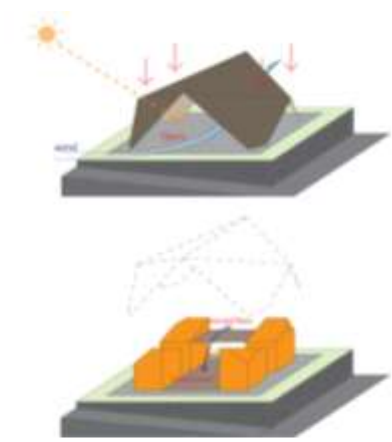

Fig. 1: Conceptual Development of Form

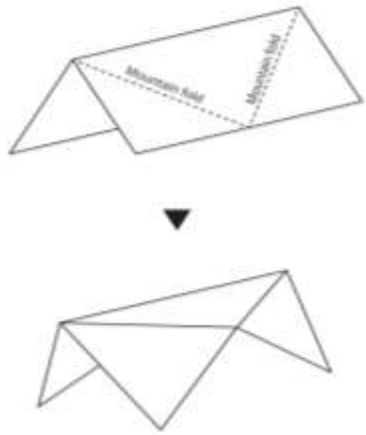

Fig. 2: Conceptual Development of Basic Fold

Improvements on origami according to John (2014) confirmed that graphics hardware have brought human-machine communication to the point where various computer models can be manipulated interactively using a graphical display as if they were real models. Virtual Reality (VR) technology has great potential for application in various fields such as design, entertainment, education, training and medicine. The idea is to implement a generative voronoi geometry as captured by David (2014), is to create a modular system that can be built through the use of mobile industrial-size 3D printing arms. Such future generations will be able to achieve with Stay Plastic, a fascinating conceptual study for generative, voronoi-shaped recycled-plastic 3D printed housing. Translating it into reality would require enormous amounts of plastic and the project would be feasible only through the implementation of new and more practical means of recycling the enormous amounts of plastic that contaminate oceans and water ways every single day on earth.

OBJECTIVES

1. To establish a reliable connection between the origami and kirigami with architectural design concepts.
2. To explore the use of three-dimensional entites in the design of spatial structures will be reviewed.

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3 To use of origami and kirigami as a method of transforming shapes in the design process and three-dimensional symmetries, which can even lead to the discovery of new forms and construction methods (Diaaelden, 2015)?

METHODOLOGY

This section has been analyzed based on sorting out by using compare (general views) and contrast (specific views) to the raised questions as tabulated below in (Table 1).

Table 1 Qualitative analysis of general views and specific views

S/no	*Questions*	*General views*	*Specific Views*
1	Suggest methods used in origami and kirigami for achieving:		
		Advanced computer graphics and computer animations	BIM, virtual and reality productions,
	Construction?	Evolution of new materials, equipment, furnishing and finishing products especially in roofing concepts.	Industrialized buildings, soft touch and character recognition systems
	Computer packages?	Computer aided design and Computer aided building	3D printing, simulations, genetic and living buildings
2	How can we apply the above in :		
	Design?	Art works, textile industry automobile industry and construction industry	Considerations and determinants of conceptualization, symbolism, bubble and functional diagrams
	Supervision?	Interactive CAD & mobile working	E- studio and VR
	Services?	Programmed alert systems for security and emergencies	Programmed building maintenance systems

3	List some applications of origami and kirigami in architecture	Aspects roof coverings, tiles, curtain walls, wall papers and ceilings of various materials	Tessellations, voronois, miura-ori, meshes, origami, space management and simulations
4	What are the advantages and disadvantages of using origami and kirigami in architecture?	Fascinates design operations and quality work, but capital intensive	Achievement of dimensional accuracy but not easily accessible and may be costly

Source: Researchers' field work, 2022

APPLICATIONS OF ORIGAMI AND KIRIGAMI

Origamis are ubiquitous in architectural design. There are theoretical, computational, and artistic challenges associated with many aspects of design that take advantage of symmetry of origami and ability to fold complex shapes. While various approaches exist, it is important to bring together good examples of practical design and the thought process of the designers who created folding and/or tiled/patterned based products with theoretical approaches so that the two may catalyze new ideas in the architectural design community. Architects love origami because it achieves what buildings rarely do: frame space through extreme economy of means. Origami artists can produce a panoply of shapes and forms using only a single sheet of paper. Their constructions are inherently structural and can even be engineered to bend, contract, and expand (architizer, 2013). Applications of origami in architecture according to Juliana and Gabriela (2007) exhibited various works of past artists and architects such as Leonardo da Vinci, who developed systematic studies on church plans with central organization, mostly based on the dihedral group, analyzing how chapels and niches could be added without disturbing the cyclic symmetry. Frank Lloyd Wright, on the other hand, used cyclic symmetry in apartment plans, such as in the Sun top Homes. She also identified occurrences of architectural structures that are similar to those origami shapes, especially in traditional Islamic architecture and in modern Brazilian architecture. The vaults of the Great Mosque in Cordoba, for example, are based on polyhedrons originated from regular octagons. The modular origami or kusudama is characterized by a regular structure. The construction of this type of origami encourages the development of creativity through experiments with colors and textures. It can be seen as a method for exploring the use of three-dimensional symmetries in the design of spatial structures. The study of three-dimensional structures led to a research on regular polyhedron, solids that are mathematically related to kusudama through the spatial symmetry. Other applications are early, latest and future as follows:

EARLY APPLICATIONS

In 2014, the Ingenia publications wrote that origami provides an elegant mechanism to package large objects into smaller spaces, an application that engineers have taken advantage of, especially in space. In missions to outer space, large objects need to be transported in narrow rockets before being unfolded to their full dimensions while in orbit. The first origami to be activated in this way was for a solar array in a Japanese research vessel launched in 1995. The solar array was folded using a pattern developed by and named after structural engineer Koryo Miura, a professor at Tokyo University, which packaged it as a compact parallelogram for its flight into space. Miura-ori is a widely used fold to pack flat sheets into a smaller space. Formed of a grid of packed parallelograms, Miura-ori is an example of an origami tessellation as well as being a form of rigid origami, as each parallelogram remains flat upon folding and unfolding. Another typical application is the Frank Llyod Wright Origami chair for the Garden Room of his residence at Taliesin West, Scottsdale, Arizona, in 1949. The design ensured the production process to be as streamlined as possible so that the entire armchair could be fabricated from a single sheet of 4 x 8 feet of laminated plywood, while at the same time guaranteeing an ergonomic, comfortable, and uniquely upholstered final product (https://www.dezeen.com/ 2018/12/ 03/taliesin-1-chair-frank-lloyd- wright-reissued-cassina/) as shown in Figure 3.

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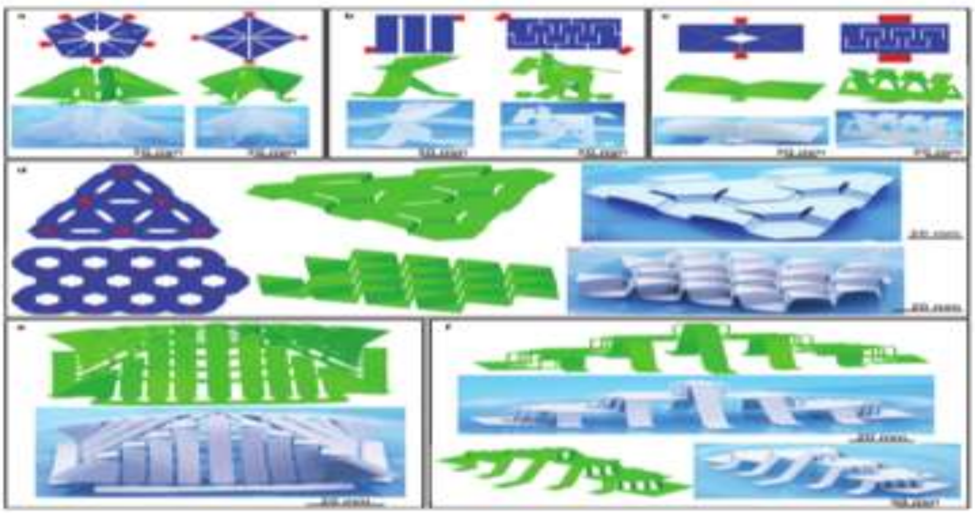
LATEST APPLICATIONS

In 2012, a pioneering metal folding company –Robo Fold, in UK worked with Zaha Hadid Architects to create a sculpture for the Venice Architecture Biennale. The company has developed a suite of software that can transform the practice of folding paper by hand into an industrial process of folding metal with robots. For each piece, the design is initially scoped out in practice with paper before moving onto computer simulations using bespoke plug-ins running on the popular Rhino and Grasshopper Computer Aided Design platforms. A flat cutting pattern is created, which is scored and cut onto a metal sheet by a Computer Numerical Control (CNC) router before the structure is folded into shape by robots programmed to carry out that particular process (Ingenia, 2014). Transformable furniture prototype performance at the kindergarten. University of Thessaly, Department of Architecture, Design Studio Folding Architecture, Sophia Vyzoviti (faculty) Pablo de Souza (teaching assistant) Eleni Marinakou, Stavroula Psomiadi and MariaTsilogianni (students) 2012. as shown in Figure 4.

FUTURE APPLICATIONS

Engineers are also interested in the application of origami to change a material's mechanical properties. Mechanical metamaterials are artificial structures whose mechanical properties are defined by their structure rather than their composition. By introducing fold patterns into materials, engineers have found a way to create tuneable materials with novel properties, such as enhanced stiffness or a negative Poisson's ratio. In 2012, the US National Science Foundation awarded a total of $26 million to 13 separate projects researching origami design to aid in the integration of self assembling systems. The use of origami in engineering is a rich and burgeoning research area and work continues in fields as diverse as computational simulations, energy-absorbing structures, mechanical metamaterials, self-folding devices and the application of origami in manufacturing. With interest in the field increasing and the sheer number of origami patterns available to investigate, it is likely there are still many more applications of origami in engineering to come (Ingenia, 2014). 3D structures inspired by origami and kirigami concepts, through the uses of creases and/or cuts. a) 2D precursors, FEA predictions, and optical images for two folding structures, transformed from kirigami designs with uniform thicknesses. b) Similar results for two structures that involve not only folding but also twisting, also transformed from kirigami designs with uniform thicknesses. c,d) Similar results for four origami structures, transformed from designs with combined uses of cuts and creases (through nonuniform thicknesses). e,f) Two highly complex 3D structures: a " Ziggurat " architecture, and a three-floor building with textured steps (Zheng *et al*, 2016) as shown in Figure 5.



RECOMMENDATIONS FOR FURTHER RESEARCH

i) There is the need in professionalism whereby computer experts team up with architects to produce more of enabling origami and kirigami concept development.

ii) More research investigations could be made possible by considering global best practices, sustainability, etc. in future.

SUMMARY & CONCLUSION

The study allowed us to have a more accurate knowledge about origami and kirigami from architectural point of view, especially in regards to its symmetry and geometry, aspects that had been noticed before but had not been clearly experienced. Most of the developments of traditional and historical origami had undergone transformations which begins with mathematics (geometry, triangulation, algorithm, decimation, algebra, circle theory) often appears to be simple to understand. However, research and investigation show that tilings and tessellation are infact complex (Jasphreet, 2009). Large percentage of the theoretical aspects of origami and kirigami are futuristic (e.g a character recognition systems that works in tandem with tessellation as natural origamis in our bodies are being transformed digitally), while others are existing practically as God-made or man-made. In order to perform architectural operations practically in the most efficient manner that will out-perform the craft-oriented ones, cutting-edge origami systems are being presently used as a technical support. The driving forces that make tessellations practical are BIM-driven CNC-controlled fabrication systems that make it possible to mass customize components of industrialized buildings (Zahner, 2008).

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